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Integrated Water Supply and Sanitation Management: Environmental Impact Assessment and Wastewater and Stormwater Treatment

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Abstract

This study assesses the environmental impact of integrated water supply and sanitation management with a focus on wastewater and rainwater treatment. The study uses an integrated methodology including comparative data analysis, evaluation of water treatment technologies and environmental modeling. The results show that the integration of different treatment technologies such as physico-chemical and biological processes significantly improves water quality, making it suitable for reuse or safe discharge into ecosystems. The study emphasizes the effectiveness of these technologies in reducing environmental pollution, especially in urban areas. In addition, the analysis demonstrates the cost-effectiveness of integrated water management approaches that reduce water consumption and treatment costs, while emphasizing the importance of complying with water quality and environmental regulations. The study also identifies the need for further technological and infrastructural innovations to improve the efficiency of water supply and sanitation systems in response to climate change and urbanization. These findings contribute to the development of sustainable water management strategies that minimize environmental impacts and promote long-term sustainability in urban and rural settings.

Keywords

Environmental impacts; Treatment technologies; Rainwater Harvesting; Urban Pollution Reduction; Regulatory requirements

Introduction

Integrated water and sanitation management is an integral part of a modern sustainable development strategy. It aims to ensure public access to clean water and efficient management of wastewater and stormwater, playing a key role in minimising negative environmental impact. In the process of assessing environmental impact, such management addresses not only water supply needs but also develops

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measures to reduce water pollution. This is achieved using a variety of treatment technologies, including physical, chemical and biological processes, which significantly improve the quality of treated water, making it suitable for reuse or safe discharge into ecosystems. This integrated approach not only contributes to environmental sustainability but also economic efficiency by optimising water consumption and reducing treatment costs.

Traditional methods of managing water supply and wastewater and rainwater treatment are often not effective enough to ensure sustainable water use and environmental protection (Skarbøvik *et al.*, 2014). Assessing the environmental impacts of an integrated approach to water and sanitation management identified the most efficient and cost-effective technologies and strategies that can minimise negative impacts on ecosystems and promote sustainable development of urban and rural areas (Floqi *et al.*, 2009). The area under study faces the challenge of the need for effective water and sanitation management in the context of urbanisation and climate change. Xiang *et al.* (2021) discussed the environmental aspects of water management, emphasising the need to comply with environmental standards for sustainable development. Mao *et al.* (2022) investigated technological innovations in wastewater treatment, proposing new approaches to improve the efficiency of treatment systems. Sarker *et al.* (2021) discussed the impact of urbanisation on water quality and the need to integrate natural water management methods. Dolan *et al.* (2021) analysed the economic aspects of water supply management by assessing the costs of developing and implementing new technologies. Nguyen *et al.* (2021) describe the use of biological processes in wastewater treatment, focusing on biodiversity in the ecosystems of wastewater treatment plants. Maulu *et al.* (2021) discussed climate change trends and their impact on the sustainability of water supply and sanitation systems.

Analysis of works by Walker, Smigaj and Tani (2021) emphasised the importance of social aspects of water management and public participation in decision-making processes. The study by Saleh, Mustaqeem and Khaled (2022) described the use of advanced technologies for stormwater treatment and management in urban areas. Liu *et al.* (2022) analysed the impact of global change on water resources and proposed strategies for adaptation to changing climate conditions. Debrah, Vidal and Dinis (2021) covered the issues of training and public education in the field of sustainable water management, addressing the importance of education in raising awareness and making environmentally responsible decisions. The researchers noted a significant reduction in water pollution due to the integration of various treatment technologies but found insufficient attention to the social aspects of management and the need for further research in the areas of cost-effectiveness and adaptation to climate change.

The study aimed to assess the environmental impacts of integrated water supply and sanitation management, including wastewater and rainwater treatment. Research goals:

1. Evaluate the effectiveness of current wastewater and rainwater treatment technologies in reducing environmental pollution, with a particular focus on their applicability in urban areas.
2. Analyze the cost-effectiveness of integrated water and sanitation management approaches, identifying potential savings in water consumption and treatment costs while maintaining compliance with environmental regulations.

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3. Assess the role of technological and infrastructural innovations in enhancing the efficiency and resilience of water management systems in the face of climate change and increasing urbanization.
4. Explore the environmental impact of integrated water management strategies, specifically examining the long-term sustainability outcomes for both urban and rural environments.

Materials and Methods

The study addressed physical, chemical and biological treatment methods to effectively remove contaminants from water to levels that meet safety standards for discharge to natural water bodies or reuse for industrial and domestic purposes. The study analysed three main aspects of water management in Albania, including general information on environmental impact assessment, wastewater treatment and stormwater management. For this purpose, specialised documents and reports were used to provide the necessary methodological framework and data for in-depth analysis.

This review involved a systematic approach to literature selection, analysis and synthesis. The authors started by identifying relevant studies through a comprehensive search of academic databases, focusing on studies related to integrated water supply and sanitation management, particularly in the area of wastewater and rainwater treatment technologies. The inclusion criteria were based on the relevance of the studies to the key themes of environmental impact assessment, urban pollution reduction and cost-effectiveness of integrated water resources management approaches. The selected literature was critically reviewed to assess the effectiveness of different treatment technologies and the role of technological innovation in improving water management systems. The synthesis of this analysis was aimed at identifying trends, gaps and potential strategies to improve the sustainability of water management practices in urban and rural settings. The review used a structured synthesis process in which findings from individual studies were systematically compared and contrasted to draw comprehensive conclusions about the state of the art in the field. This approach allowed the authors to integrate different perspectives and identify common themes as well as unique insights that contribute to the development of more effective and sustainable water management strategies.

The study by Bako, Cani and Cobani (2002) provided basic principles and methodologies for environmental impact assessment. The study examined various aspects of assessment methodologies, Environmental Impact Assessment (EIA) procedures and examples of their application in specific projects. This was used to identify the key aspects necessary to minimise negative environmental impacts and comply with safety standards. The data of the Food and Agriculture Organization (2018) provided strategic information on plans and actions in the field of water resources management in Albania. Wastewater treatment strategies, including an analysis of existing treatment technologies, their effectiveness and proposals for improvement, were prioritised. The results of the analysis revealed the potential for reducing wastewater treatment costs and improving wastewater quality. The data from The World Bank (2022) overviews the current status and strategies for stormwater management in Albania. The study included an assessment of existing rainwater collection and drainage

systems, methods of minimising flooding and adapting to changing climate conditions. Recommendations for improving stormwater management included suggestions for using green infrastructure and strengthening engineering solutions.

The analysis of general information on EIA in Albania was conducted to assess the effectiveness of existing procedures and practices for identifying, predicting and mitigating environmental impacts of various projects. The assessment included several key criteria: level of access to safe drinking water, level of access to sanitation, per capita water consumption, wastewater discharge and water and sanitation sector expenditure. Wastewater treatment in Albania was reviewed to determine the current status and efficiency of wastewater treatment systems. The analysis included an assessment of the technologies used, the extent of their implementation and the results of the treatment. This identified shortcomings and provided recommendations for improving wastewater treatment to minimise its negative impact on the environment and improve water quality. Stormwater management in Albania was analysed to assess existing strategies and methods for controlling rainwater runoff. The analysis included an assessment of the use of natural and engineering systems to minimise flooding and pollution. The study identified the most effective practices and suggested improvements for stormwater management in the context of urbanisation and climate change.

Particular attention was also devoted to stormwater management, especially in urban areas where impermeable urban surfaces contribute to increased runoff and water pollution. The use of green infrastructure, such as green roofs, permeable pavements and specialised ponds, can significantly reduce the negative impact of stormwater runoff on ecosystems and urban infrastructure in general. In addition, the cost-effectiveness of integrated approaches to water and sanitation management was assessed. Investments in modern water treatment and management technologies can significantly reduce operating costs and water consumption, which is an important aspect of sustainable urban development.

Results

Effectiveness of Wastewater and Rainwater Treatment Technologies

Integrated water and sanitation management includes comprehensive approaches to managing water resources, ensuring adequate supply and effective treatment of wastewater (Figure 1) and stormwater (Figure 2).

Environmental impact assessment is an integral part of any project involving the use of natural resources or infrastructure development. It assesses the potential environmental impacts of the proposed project and develops measures to prevent or minimise them. The main goal of EIA is to ensure sustainable development that covers the interests of both current and future generations. The EIA process starts with the identification of potential environmental impacts of a project. At this stage, information is gathered on the natural, socio-economic and cultural characteristics of the area where the project is planned to be implemented. An important part of this stage is the involvement of stakeholders, including residents, authorities and non-governmental organisations. Their participation identifies hidden problems and addresses the views of those who may be

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affected by the project. Once potential impacts are identified, they are forecasted. This includes modelling various scenarios and assessing how the project may affect the environment. It is necessary to cover a wide range of factors, such as changes in air and water quality, impacts on biodiversity, soils, and landscapes, as well as social and economic aspects. Forecasting demonstrates possible negative consequences in advance and prepares measures to mitigate them.

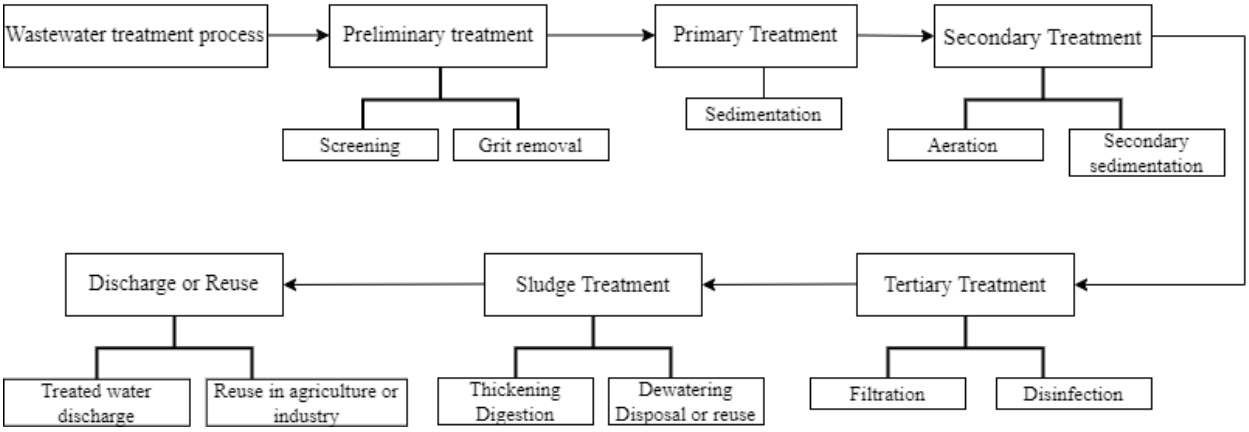

Figure 1: Processes of wastewater treatment

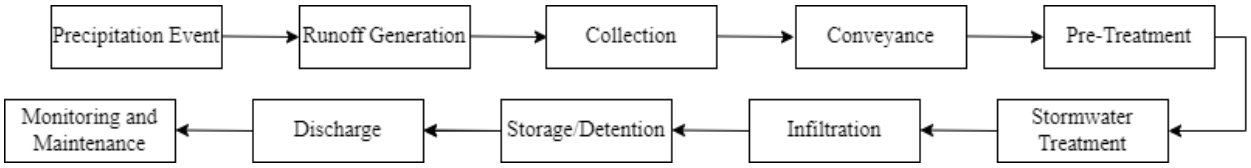

Figure 2: Stormwater management processes

Mitigation of environmental impact is a key stage of EIA. This includes the development and implementation of measures to prevent or minimise the negative effects of the project. For instance, the construction of an infrastructure facility may involve the use of technologies that reduce pollutant emissions or the creation of green areas to compensate for the loss of natural ecosystems. In some cases, it is possible to adapt the project to reduce its impact on sensitive ecosystems or cultural sites. To ensure the effective implementation of mitigation measures, the EIA process needs to be monitored and managed. Monitoring tracks the implementation of planned measures and evaluates their effectiveness. In case of deviations from the planned indicators, corrective actions are developed. Managing the EIA process requires constant interaction between different stakeholders and flexibility in decision-making. An important aspect of EIA is its role in ensuring sustainable development. Sustainable development requires a balance between economic growth, social justice and environmental protection. EIA contributes to this balance by ensuring that environmental and social factors are accounted for in the planning and implementation of projects. This prevents long-term negative consequences and creates conditions for a prosperous future.

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Cost-Effectiveness of Integrated Water Management Approaches

Albania, similarly too many other countries, faces challenges in managing wastewater and rainwater. Inadequate infrastructure, outdated technology and a growing population lead to water pollution, flooding and other problems. An integrated approach to wastewater and rainwater management can help solve these problems, but it is necessary to determine the economic costs associated with its implementation (Table 1). The introduction of more efficient water treatment technologies can reduce operating costs for chemicals and electricity by up to 20-30%. Improved wastewater treatment facilities reduce pollution levels in rivers and lakes, which has a positive impact on ecosystems and public health. The construction of water reservoirs and rainwater harvesting systems mitigates droughts and ensures a stable water supply, which is especially relevant in agricultural regions. Cleaner water reduces the risk of diseases associated with contaminated water, leading to lower healthcare costs. The creation of new jobs in water treatment and water management contributes to the development of the local economy.

Table 1: Economic cost analysis

Cost category	*Description*	*Example*	*Estimated costs (in US dollars)*	*Estimated benefits and efficiency*
Capital expenditure				
Modernisation of existing sewage systems	Expenditures on construction or modernisation of infrastructure	Construction of new rainwater collection systems	7.5 million per project	Reducing the risk of flooding, improving water quality
Creation of water reservoirs	Expenditures on the construction of water bodies and reservoirs	Construction of reservoirs for rainwater	2.5 million per reservoir	Improving water supply, reducing water shortages
Operating costs				
Costs of chemicals for wastewater treatment	Infrastructure operation and maintenance costs	Procurement of chemicals for wastewater treatment plants	75 thousand per year	Improving water treatment quality, reducing pollution
Personnel costs	Remuneration of employees	Salaries of employees of treatment facilities	350 thousand per year	Increase employment, improve services
Electricity costs	Payment for electricity consumption	Electricity costs for pumping stations	200 thousand per year	Efficient operation of systems, reduced energy costs using renewable energy sources
Research and development expenditure	Expenditure on the development of new technologies and solutions	Research into biological wastewater treatment methods	750 thousand per project	Developing more efficient technologies, reducing operating costs

Training costs	Expenditure on staff training in new technologies and methods	Training in the operation of rainwater harvesting systems	75 thousand per training	Improving staff skills, reducing errors and accidents

Source: Based on Eftimi, Shehu, and Sara (2023)

Environmental impact assessment is substantial in modern projects aimed at using natural resources or developing infrastructure (Prus and Sikora, 2021). It identifies, predicts and mitigates potential environmental impacts, contributing to sustainable development and protecting the interests of both current and future generations. The EIA process requires careful planning, stakeholder engagement and ongoing monitoring to ensure effective implementation of environmental protection measures (Table 2).

Table 2: General information on EIA in Albania for 2020

Indicator	*Value*
Level of access to safe drinking water	98% of the population
Level of access to sanitation	98% of the population
Water consumption per capita	310 m^3/year
Wastewater discharge	80% of wastewater is not treated
Expenditure on the water and sanitation sector	2% of GDP

Source: Based on Hoxha *et al.* (2022)

Wastewater treatment is a substantial component of the water and sanitation management system (Table 3). It removes pollutants from wastewater to make it safe for discharge into natural water bodies or for reuse. Efficient wastewater treatment maintains ecological balance, prevents water pollution and ensures sustainable use of water resources.

Table 3: Wastewater treatment in Albania in 2020

Indicator	*Value*
Number of wastewater treatment plants	100
Capacity of treatment facilities	500,000 m^3/day
Cleaning methods	Biological treatment, chemical treatment, filtration
Level of wastewater treatment	70%

Source: Based on Hoxha *et al.* (2022)

Modern wastewater treatment methods include physical, chemical and biological processes. Each of these methods is key to achieving the cleaning goal and has unique advantages. Physical methods of treatment, such as sedimentation and filtration, are based on the removal of solids and suspended solids from wastewater (Ahmed *et al.*, 2021). Sedimentation allows coarse particles to settle, which are then removed from the water. This method is easy to use and cost-effective, but it is not always able to remove fine particles and dissolved solids. Filtration, on the other hand, involves passing water through porous materials that trap pollutants. Filtration is more effective at removing fine particles and can be used in combination with other methods to achieve high levels of cleaning. Chemical treatment methods include the use of various reagents to neutralise

or remove contaminants (Dubey *et al.*, 2021). Coagulation and flocculation, for instance, are used to aggregate small particles into larger ones that can then be easily removed from the water. Oxidation and disinfection using chlorine or ozone kill pathogens and oxidise organic contaminants. Chemical methods can be highly effective but require careful control of reagent dosage and can be costly.

Biological treatment methods are based on the use of microorganisms to decompose organic matter in wastewater (Barjasteh *et al.*, 2021). This process is called biodegradation and includes aerobic and anaerobic methods. Aerobic methods, such as activated sludge, use oxygen to stimulate the growth of microorganisms that break down organic matter. Anaerobic methods, such as methanogenesis, take place in the absence of oxygen and can be effective in removing difficult-to-degrade organic compounds. Biological methods are environmentally friendly and can be cost-effective, especially when treating large volumes of wastewater. Effective wastewater treatment not only prevents water pollution but also enables the reuse of treated water (Klemo *et al.*, 2021). Wastewater can be reused for a variety of purposes, such as agricultural irrigation, industrial processes and even domestic use after additional treatment (Hulevskyi and Postol, 2022). This contributes to the rational use of water resources and reduces the pressure on natural water sources. In addition, modern wastewater treatment systems can be integrated with other technological processes to increase their efficiency. For instance, a combination of biological and chemical methods can achieve a higher level of purification than using each of them separately. Innovative technologies, such as membrane processes and advanced oxidation methods, are also being used in wastewater treatment systems, providing new opportunities to improve the quality of treated water.

Wastewater treatment is substantial in ensuring environmental safety and sustainable use of water resources (Huseynov *et al.*, 2024). Physical, chemical and biological treatment methods, such as sedimentation, filtration and biodegradation, effectively remove pollutants from wastewater, making it safe for discharge or reuse. Efficient wastewater treatment systems preserve water bodies, prevent environmental pollution and improve the rational use of water resources in various spheres of life. Stormwater management is a substantial challenge for cities and rural areas, especially in the context of growing urbanisation and climate change (Table 4). Stormwater resulting from precipitation can lead to flooding, soil erosion and water pollution, which negatively affects the environmental condition and sustainability of infrastructure. The goal of stormwater management is to control runoff to minimise flooding and pollution while protecting the environment and improving the quality of life.

Table 4: Stormwater management in Albania for 2020

Indicator	*Value*
Area covered by stormwater systems	20% of the urban area
Stormwater management methods	Green infrastructure, stormwater drains, drainage systems
Challenges in stormwater management	Flooding, soil erosion, water pollution

Source: Based on Hoxha *et al.* (2022)

One of the key approaches to stormwater management is the use of green infrastructure. Green infrastructure includes natural elements and processes, such as green roofs, biofilters, rain gardens and restored water bodies. These solutions absorb, retain and filter stormwater, reducing the volume of runoff and preventing it from flowing rapidly into sewer systems and water bodies. Green roofs, for example, can retain a significant amount of rainwater, reducing the burden on drainage systems and improving the microclimate in urban areas. Biofilters and rain gardens clean stormwater by removing pollutants and nutrients, which improves water quality and prevents eutrophication of water bodies. Engineering systems are also substantial in stormwater management. One of the most effective engineering solutions is stormwater collection ponds. These ponds accumulate and retain water, preventing its rapid outflow and reducing the risk of flooding. They also settle solid particles and partially purify water before it reaches natural water bodies. Permeable pavements such as porous asphalt or concrete are also an important element of engineering systems. They allow water to be absorbed into the soil, reducing runoff and renewing underground aquifers. The use of such coatings is particularly effective in urban environments, where traditional asphalt or concrete surfaces contribute to rapid and uncontrolled water runoff.

A combination of green infrastructure and engineering systems is the best strategy for stormwater management (Kravchenko and Tkachenko, 2024). This integrated approach allows not only to effectively control the volume and rate of runoff but also to improve water quality by promoting its natural filtration and purification. Notable, stormwater management requires the integration of different methods and technologies, as well as consideration of local climatic, geological and urban conditions. One example of successful stormwater management is the Green Street system in Portland, Oregon, USA. This project includes the use of rain gardens, biofilters and permeable pavements to manage water runoff (Tanaka *et al.*, 2022). As a result of the project, the volume of stormwater entering the sewerage system was significantly reduced, water quality in rivers was improved and the risk of flooding was reduced.

Stormwater management is an important aspect of sustainable urban and rural development (Alim *et al.*, 2022). The use of green infrastructure and engineering systems can be used to effectively control water runoff, minimise flooding and pollution, and contribute to improving the environment and quality of life. An integrated approach to stormwater management requires constant interaction between different stakeholders, adaptation to changing climate conditions and the introduction of innovative technologies and solutions. Urbanisation, accompanied by urban growth and infrastructure development, is significantly altering natural landscapes and introducing major changes to the water cycle. One of the main effects of urbanisation is the increase in impermeable surfaces such as roads, pavements, roofs and car parks. These surfaces impede the natural infiltration of rainwater into the ground, increasing the volume and rate of stormwater runoff. As a result, many environmental and infrastructural problems arise related to water management and environmental protection.

One of the most visible effects of urbanisation is an increase in the risk of flooding. Impermeable surfaces are unable to absorb water, which leads to a rapid and uncontrolled outflow of rainfall. As a result, even relatively light rains can cause localised flooding of streets and basements, endangering people and damaging property.

The situation is exacerbated by heavy rainfall, leading to large-scale flooding that can destroy infrastructure, destroy crops and cause significant economic losses. In addition, urbanisation is leading to a deterioration in the quality of water resources. Stormwater flowing over impermeable surfaces collects various pollutants, such as oils, heavy metals, chemicals, garbage and organic waste. These pollutants end up in water bodies, rivers and lakes, causing pollution and damage to ecosystems. Contaminated water can lead to the death of fish and other aquatic organisms, a decrease in the quality of drinking water and a deterioration in the living conditions of people living near contaminated water bodies (Bogoliubov *et al.*, 2023).

Increased stormwater runoff also affects the hydrological regime of rivers and water bodies. Rapid water outflows lead to an increase in peak flows in rivers, which can cause bank erosion, channel destruction and changes in the hydrographic network. This disrupts the natural self-purification processes of water bodies and impairs their ability to support biodiversity. Aquatic ecosystems are becoming more vulnerable to the impact of pollutants and climate change, which leads to a decrease in their resilience and productivity. To mitigate the negative impacts of urbanisation and improve stormwater management, integrated approaches and technologies are needed. One effective solution is the use of green infrastructure, including elements such as green roofs, biofilters, rain gardens and permeable pavements. These technologies help to retain and filter stormwater, reduce runoff and improve water quality. Green roofs, for example, help absorb rainwater and reduce air temperature, which is especially important in urban heat islands.

Technological and Infrastructural Innovations in Water Management

Engineering systems are also significant in managing stormwater in urban areas. Stormwater catchment ponds, permeable asphalt and concrete, as well as water retention and infiltration systems help control runoff and reduce the load on drainage systems. These solutions can be integrated into urban infrastructure, creating sustainable and environmentally friendly living conditions for the population. Urbanisation and the increase in impermeable surfaces lead to a significant increase in stormwater runoff and water pollution (Agrawal, Panda and Bhuyan, 2021). This causes many environmental and infrastructural problems, such as flooding, deterioration of water quality and disruption of the hydrological regime of rivers. To solve these problems, integrated approaches are needed, including the use of green infrastructure and modern engineering systems. Such measures mitigate the negative effects of urbanisation, improve water management and create more sustainable and environmentally friendly living conditions in cities. Sustainability is one of the key principles of modern water and sanitation management. With a growing population, urbanisation and climate change, efficient use of natural resources, reuse of treated water and minimisation of energy consumption are becoming essential elements of sustainable development. Addressing these aspects not only meets the current needs of society but also preserves resources for future generations while reducing the negative impact on the environment.

One of the most important components of sustainable water management is resource efficiency. Water resources are limited, and their rational use is key to ensuring a sustainable water supply. This includes the introduction of technologies to reduce water losses, improve water management and reduce water consumption in the domestic,

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industrial and agricultural sectors. For example, the use of modern drip irrigation systems in agriculture can significantly reduce the amount of water required for irrigation and increase yields. In urban areas, installing water-saving devices such as low-flow faucets and shower heads helps to reduce water consumption without compromising on the comfort of the population. Reuse of treated water is another important aspect of sustainable water management. Modern wastewater treatment technologies produce high-quality water suitable for various purposes. The treated water can be reused in agriculture, industry and even for domestic use after additional treatment. This reduces the pressure on natural water sources, reduces water supply costs and reduces the volume of wastewater requiring treatment. For instance, in some cities, treated wastewater is used to irrigate parks and green spaces, which helps to preserve fresh water for drinking purposes. In industrial processes, water reuse reduces the consumption of fresh water and reduces the amount of wastewater that needs to be disposed of.

Minimising energy consumption is an important aspect of sustainability in water and sanitation management (Doroshkevich *et al.*, 2019). The processes of water purification and distribution, as well as wastewater treatment, require significant energy inputs. The use of energy-efficient technologies and renewable energy sources helps to reduce these costs and reduce greenhouse gas emissions. For instance, the introduction of energy-efficient pumps and automation systems in water supply and sewerage helps to reduce energy consumption. The use of renewable energy sources such as solar panels and biogas to power wastewater treatment plants reduces dependence on fossil fuels and reduces the carbon footprint. In addition, some wastewater treatment systems can produce energy in the form of biogas, which can be used to generate electricity or heat. Sustainable water management requires a comprehensive approach, including the introduction of innovative technologies, improved governance and public education. It is also necessary to account for local climatic, geographical and socio-economic conditions when developing and implementing sustainable water use strategies. International cooperation and exchange of experience are also substantial in promoting sustainable practices and technologies.

Sustainability in water and sanitation management includes an emphasis on resource efficiency, reuse of treated water and minimisation of energy consumption (Fito and Van Hulle, 2021). These aspects contribute to the conservation of natural resources, improvement of the environment and sustainable development. The introduction of modern technologies, the use of renewable energy sources and the rational management of water resources are key elements in achieving sustainability and creating favourable living conditions for present and future generations. Compliance with regulatory requirements is a critical aspect of sustainable water and sanitation management. These requirements set standards for water quality and environmental protection that aim to ensure public safety and health, as well as the preservation of ecosystems. With increasing pressure on water resources due to population growth, urbanisation and climate change, compliance with local, national and international standards is critical to achieving sustainable development and protecting natural resources (Adamkulova and Aitbaev, 2024).

Local regulatory requirements usually address the specific conditions of the region, such as climate, geography, infrastructure and socio-economic factors. These requirements

may include drinking water quality standards, wastewater discharge regulations, water use standards and water protection measures. Compliance with local regulations can account for the unique characteristics of the region and develop effective water management and environmental protection measures. For instance, in areas where water resources are scarce, strict water conservation and reuse of treated water can be introduced. National standards for water quality and environmental protection are usually developed by government agencies and set general rules and regulations for the whole country. These standards provide uniform requirements for water quality, water body protection and water resource management at the national level. National regulations may include requirements for the content of pollutants in water, rules for industrial wastewater treatment, and measures to protect aquatic ecosystems. Compliance with national standards ensures high water quality and reduces the negative impact on the environment, as well as creating conditions for sustainable development and improving the quality of life (Denysiuk *et al.*, 2022).

International standards and agreements are substantial in ensuring global sustainability and protection of water resources (Scanlon *et al.*, 2023). These standards are developed by international organisations such as the World Health Organisation (WHO), the United Nations (UN) and the International Organisation for Standardisation (ISO). International standards set out general requirements for water quality, environmental protection and water management that must be met by all member countries. Compliance with international standards harmonises national regulations and improves cross-border cooperation and exchange of experience between countries. This is especially important in the face of global challenges such as climate change, water scarcity and water pollution, which require joint efforts to address. Compliance with regulatory requirements also stimulates the development and implementation of new technologies and innovations in water management and sanitation. Companies and organisations striving to meet water quality and environmental standards have to find effective and environmentally friendly solutions. This leads to the development and implementation of advanced water treatment technologies, water management systems and methods to reduce water and energy consumption. For example, modern technologies for membrane filtration and biological wastewater treatment can significantly improve water quality and reduce the burden on natural water bodies.

Regulatory compliance is a key element of sustainable water and sanitation management. Local, national and international water quality and environmental standards establish rules and regulations to ensure public safety and health and to preserve ecosystems. Compliance with these requirements accounts for the specific conditions of the region, ensures uniform standards at the national level and facilitates global cooperation and exchange of experience. In addition, compliance with regulatory requirements stimulates the development and implementation of innovations and new technologies, which contributes to improving water quality, environmental protection and sustainable development. Integrated approaches ensure sustainable management of water resources, balancing environmental impacts with public needs for water supply and sanitation.

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Discussion

Integrated water and sanitation management is a comprehensive approach that combines water management, wastewater and stormwater treatment and environmental impact assessment. This approach has become necessary in the context of growing urbanisation and climate change, which put significant pressure on water resources.

Traditional methods of water and sanitation management are not always able to cope effectively with the challenges of today, which require more integrated and sustainable solutions. This aspect was also considered by Koop *et al.* (2022) concluding that integrated water management in urbanisation has become vital for sustainable urban development. The rapid expansion of urban areas is increasing the demand for water and putting pressure on water resources, causing problems such as pollution, water depletion and deterioration of water quality. Integrated water management refers to the coordinated management of water resources at all levels, involving different stakeholders such as government agencies, the private sector and non-governmental organizations (NGO). This approach ensures the rational use of water, minimisation of negative environmental impacts and improved water security. The application of integrated management requires the introduction of modern monitoring and management technologies, the creation of effective policies and regulations, and the development of infrastructure to improve water supply and wastewater treatment.

Moreover, a study conducted by Mishra *et al.* (2021) noted that, in modern conditions, integrated water supply and treatment solutions play a key role in ensuring sustainable and safe water use. Traditional methods of water supply and treatment often fail to cope with the challenges posed by population growth, climate change and environmental pollution. Innovative approaches are therefore needed, including the use of advanced technologies such as membrane filters, reverse osmosis systems and ultraviolet (UV) disinfection, as well as the integration of renewable energy sources to reduce the carbon footprint. Another important aspect is the creation of sustainable water treatment and supply systems that account for local conditions and ensure long-term reliability and cost-effectiveness. Integrated solutions also include water management based on an ecosystem approach, which protects natural water bodies and improves water quality, as well as increases adaptability to changing climate conditions, which is consistent with the results of this study.

Environmental impact assessment is a crucial component of integrated water supply management, as it helps to identify and mitigate potential negative impacts of various projects and activities. Environmental assessment includes analysing the current state of the environment, forecasting possible changes and developing measures to mitigate negative impacts (Shahini *et al.*, 2024). It is necessary to note that compliance with regulatory requirements and water quality standards plays a key role in the environmental assessment process, ensuring that projects comply with national and international environmental standards. This was also investigated by Shams and Muhammad (2022) where the results confirmed that environmental impact assessment is substantial in water management, helping to identify potential environmental risks and develop mitigation measures. This process includes a comprehensive analysis of the potential impacts of various projects and activities on aquatic ecosystems and water quality. Environmental

impact assessment can be used to address factors such as water pollution, changes in hydrological regimes and impacts on biodiversity, which contributes to informed decision-making and planning for sustainable use of water resources.

Nita, Fineran and Rozylowicz (2022) also determined that EIA can be used for a detailed analysis of environmental impacts associated with infrastructure development, industry and other activities that affect water resources. This process includes assessing direct and indirect impacts and developing strategies to mitigate them. Mitigating measures may include improving wastewater treatment technologies, implementing water management practices and restoring damaged ecosystems. Environmental impact assessment minimises negative environmental impacts by maintaining a balance between economic development and the conservation of natural resources. It is worth noting that environmental impact assessment not only reduces negative impacts on water resources but also promotes public participation and awareness. The involvement of local communities and environmental organisations makes decision-making more transparent and inclusive, which increases trust and support for projects aimed at sustainable water management and ecosystem protection.

Wastewater treatment is another important element of integrated management (Doroshkevich *et al.*, 2017). Wastewater containing various pollutants can have a serious negative impact on aquatic ecosystems and public health. Modern treatment systems use physical, chemical and biological methods to remove contaminants and improve water quality. Efficient wastewater treatment not only prevents water pollution but also allows the treated water to be reused, which is especially important in a water-scarce environment (Litynska, Dontsova and Gusak, 2023; Lyubchyk *et al.*, 2015). This aspect was addressed by many scholars, including Abuhasel *et al.* (2021) emphasising that modern wastewater treatment methods include the use of advanced technologies such as membrane bioreactors, ultrafiltration, reverse osmosis and ultraviolet disinfection systems. These technologies provide a high degree of purification, removing not only suspended solids and organic matter but also microorganisms, heavy metals and micro-contaminants. The use of biological treatment with the addition of specialised bacteria also allows for the effective decomposition of organic contaminants. The integration of such technologies into wastewater treatment plants can significantly improve the quality of treated water, making it safe for reuse or release into water bodies.

Rashid *et al.* (2021) concluded that effective wastewater treatment is critical for environmental protection and public health. It prevents water pollution, reduces public health risks associated with pathogens and toxic substances, and maintains the biodiversity of aquatic ecosystems. In addition, the high degree of purification allows the treated water to be used for various purposes, such as irrigation, technical water supply and even drinking purposes, which is especially relevant in the context of water scarcity. Thus, the introduction of modern wastewater treatment methods is a primary element of sustainable water use and water resources protection. These results confirm the conducted study, as they demonstrate that modern wastewater treatment methods are effective in removing a wide range of pollutants, ensuring high quality of treated water. This is especially important in the context of integrated water management, where clean water is a primary element of sustainable urban development. This is especially important in the context of integrated water management, where clean water is a key

element of sustainable urban development. In addition, effective wastewater treatment minimises environmental risks and improves public health, which confirms the importance of introducing advanced technologies and integrated solutions in the water supply and water treatment sector.

Stormwater management is a major challenge for cities where most of the surface is covered with impermeable materials such as asphalt and concrete. This leads to an increase in runoff and water pollution (Petruk and Bilichenko, 2023). The integration of natural and engineered solutions, such as green infrastructure, permeable pavements and specialised ponds, effectively manages stormwater, reducing the risk of flooding and improving water quality. Xu, Randall and Fryd (2023) addressed this phenomenon, noting that effective stormwater management in cities is becoming increasingly important in the face of increasing rainfall intensity and urbanisation. Traditional drainage systems often fail to cope with the volume of water during heavy rains, leading to flooding, soil erosion and water pollution (Totubaeva *et al.*, 2023). Modern approaches include the integration of methods such as permeable pavements, rainwater storage and reuse systems, and the construction of bio-ponds and green roofs. These methods reduce the load on the urban drainage system, improving control over stormwater flows and reducing risks to urban infrastructure and ecosystems.

Moreover, Kaur and Gupta (2022) determined that green infrastructure is substantial in innovative stormwater management, offering natural and semi-natural solutions to effectively control water flows. Green infrastructure elements, such as rain gardens, green roofs, biofilters and restored ponds, not only retain and filter rainwater but also contribute to improving the urban environment, reducing the heat island effect, increasing biodiversity and improving air quality. These innovations ensure more sustainable and environmentally friendly stormwater management, maintaining a balance between urban infrastructure development and the preservation of natural ecosystems. These data are consistent with the theses presented in the previous section. Employment of modern methods of water treatment and management, including the integration of advanced technologies and green infrastructure, contributes to the achievement of sustainable water use and improved water quality (Easa *et al.*, 2024; Nematov *et al.*, 2023). This confirms the need for an integrated approach to water management, including both traditional engineering solutions and innovative natural methods. The implementation of such approaches successfully addresses the challenges of urbanisation and climate change, ensuring reliable and efficient management of water and stormwater resources in cities.

One of the key aspects of integrated management is economic efficiency. Investments in modern water treatment and management technologies can lead to significant economic benefits (Tikhonova *et al.*, 2008). For instance, the reuse of treated water reduces water consumption, and improved wastewater treatment reduces the cost of pollution remediation. In addition, the integration of sustainable solutions into urban infrastructure contributes to long-term economic stability and reduces the cost of maintaining water and sanitation systems. Ahmad *et al.* (2021) determined that modern technologies in water supply, such as membrane filters, reverse osmosis systems and smart water networks, bring significant economic benefits. These technologies improve water efficiency, reduce losses and leakage, and reduce treatment and transport costs.

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Investments in modern water supply systems can significantly improve the situation by reducing operating costs, improving reliability and extending the operational period of the infrastructure (Asgerov *et al.*, 2022).

In addition, the high quality of water provided by these technologies reduces the cost of medical services and improves the overall health of the population, which is also of economic importance. It is worth noting the research by Li *et al.* (2022) which also showed that sustainable solutions, such as water reuse, implementation of water-saving technologies and green infrastructure, substantially assist in ensuring the economic efficiency of water systems. These approaches can be used to reduce operating costs, minimise environmental impact and create conditions for long-term reliability of water supply. For instance, reusing treated wastewater for irrigation or industrial needs reduces freshwater consumption and reduces the load on water treatment plants. Green infrastructure, in turn, reduces the cost of building and maintaining traditional drainage systems while improving the environmental sustainability of cities. Comparing the data obtained by the study, it is possible to conclude that sustainable water supply technologies and cost-effective solutions in water system management not only help to reduce operating costs and improve the overall efficiency of infrastructure but also create favourable conditions for sustainable development of urban and rural areas. Implementation of such solutions requires an initial investment, but in the long run, they lead to significant economic and environmental benefits, reduce dependence on limited water resources and help reduce the ecological footprint of human activity. Thus, the integration of sustainable approaches into water management is a necessary step to ensure the sustainable development of modern societies.

The review identifies a critical need for a more integrated and adaptive framework that strategically combines different treatment technologies and aligns them with specific environmental, economic, and regulatory contexts. A key insight is the concept of "adaptive integration," which advocates for water management systems with built-in flexibility to incorporate new technologies and respond dynamically to environmental changes. This approach contrasts with static models, promoting systems that evolve with technological advancements and environmental needs. Additionally, the review introduces "sustainability convergence," where the intersection of technological innovation, economic efficiency, and environmental protection becomes a guiding principle for decision-making. By proposing these frameworks, the discussion redefines the role of technology and infrastructure, setting the stage for future research and policy development that emphasizes flexibility, resilience, and sustainability in water management.

In conclusion, integrated water supply and sanitation management is a comprehensive and multi-level approach aimed at ensuring the sustainable use of water resources. This approach requires the employment of advanced technologies, strict compliance with regulatory requirements and the introduction of innovative solutions for water management. In the context of global environmental challenges and urbanisation, integrated management is becoming a primary development vector for ensuring environmental safety and prolonged sustainable development of cities and rural areas.

Conclusions

This review underscores the critical importance of adopting an integrated and adaptive approach to water and sanitation management, especially in the context of urbanization and climate change. The findings demonstrate that while individual treatment technologies are effective, their full potential is realized when they are part of a cohesive, flexible management system that can adapt to environmental changes in real time. The concept of "adaptive integration" highlighted in this review offers a framework for designing water management systems that not only address current environmental challenges but also anticipate future needs. Furthermore, the introduction of "sustainability convergence" emphasizes the need to balance technological innovation, economic efficiency, and environmental protection in water management practices.

The implications of these findings are significant for policymakers, urban planners, and environmental managers, as they suggest a shift from static, one-size-fits-all solutions to more dynamic, context-sensitive strategies. Future research should focus on developing and testing models of adaptive integration in various environmental settings, particularly in regions facing rapid urbanization or significant climate-related risks. Additionally, research should explore the economic and regulatory mechanisms that can support the widespread adoption of sustainability convergence in water management practices. By pursuing these directions, future studies can contribute to the development of more resilient and sustainable water management systems that effectively address both present and future challenges.

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Author's Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	Yes
Critical revision of the article/paper	No	Yes
Editing of the article/paper	Yes	Yes
Supervision	Yes	No
Project Administration	No	Yes
Funding Acquisition	No	No
Overall Contribution Proportion (%)	55	45

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has involved dairy cows (body or organs) for experimentation. The research was not based on laboratory experiment involving cattle. Other contexts of animals were only indirectly covered through literature review. Therefore, an ethical obligation of ARRIVE applies in cases of this study or written work. The ARRIVE Checklist is appended.

Research on Indigenous Peoples and/or Traditional Knowledge
The author(s) solemnly declare(s) that this research has not involved Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, prior informed consent (PIC) of the respondents or a Self-Declaration in this regard is not applicable for this article.

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